



## Discussion

## Diversity regained: Precautionary approaches to COVID-19 as a phenomenon of the total environment



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## HIGHLIGHTS

- Cazzolla-Gatti et al. 2020 described socioeconomic impacts of the COVID-19 pandemic.
- Studies call for systemic approaches to avoid unintended consequences.
- Precautionary frameworks mitigate damages of catastrophic events.
- We discuss systemic and precautionary solutions in systems affected by the pandemic.

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## ABSTRACT

As COVID-19 emerged as a phenomenon of the total environment, and despite the intertwined and complex relationships that make humanity an organic part of the Bio- and Geospheres, the majority of our responses to it have been corrective in character, with few or no consideration for unintended consequences which bring about further vulnerability to unanticipated global events. Tackling COVID-19 entails a systemic and precautionary approach to human-nature relations, which we frame as regaining diversity in the Geo-, Bio-, and Anthropospheres. Its implementation requires nothing short of an overhaul in the way we interact with and build knowledge from natural and social environments. Hence, we discuss the urgency of shifting from current to precautionary approaches to COVID-19 and look, through the lens of diversity, at the anticipated benefits in four systems crucially affecting and affected by the pandemic: health, land, knowledge and innovation. Our reflections offer a glimpse of the sort of changes needed, from pursuing planetary health and creating more harmonious forms of land use to providing a multi-level platform for other ways of knowing/understanding and turning innovation into a source of global public goods. These exemplary initiatives introduce and solidify systemic thinking in policymaking and move priorities from reaction-based strategies to precautionary frameworks.

## 1. Introduction

The COVID-19 pandemic has been raging across the planet, resulting in deep and widespread social and economic disruption. Although pathogens have been a constant threat to global health throughout history and to some extent shaped society itself (Snowden, 2019), the potentialization of

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numerous non-medical factors and their intricate, complex, and interdependent dynamics have been increasingly influencing the pace of emergence of pandemics and their expected devastating outcomes over the 21st century (Brooks et al., 2019). Understood as a phenomenon of the total environment (i.e., bearing feedback mechanisms which affect the Geo-, Bio-, and Anthroposphere), the COVID-19 pandemic reveals such intricacies and interdependencies at local, regional, and planetary levels. Acknowledging how these dynamics are intertwined calls for precautionary and systemic solutions which move beyond battling the disease itself, and rather deal with the pre-conditions that underpin its emergence. Indeed, the pandemic is a manifestation of human-induced preconditions jointly leading to the depletion of cultural, biological, and geochemical diversity which, in turn, prompts the accumulation of destabilizing stressors that feed back into social, economic, and political dynamics (Cazzolla Gatti et al., 2021). We suggest here that it is by learning how to mobilize these types of diversity on multiple scales and in different contexts that we might be able to provide precautionary approaches and address the negative implications of the current and future pandemics.

In contrast, business-as-usual, when applied to a global pandemic, shows a disregard towards the complexity of this phenomenon of the total environment. The current emphasis is mainly on its medical implications, undoubtedly a key factor in containing the virus, but this often deters focus from systemic and long-term implications of current decisions and interventions. Responses to global emergencies usually prompt even more control and reductionism in the way solutions are designed and implemented. There is also a trend of reducing the number of voices heard and perspectives taken into consideration during deliberation and decision-making processes. Such reactions do not take into account the multiple feedback loops between the Geo-, Bio-, and Anthroposphere (Cazzolla Gatti et al., 2021), such as couplings between the pandemic and climate change (Beyer et al., 2021; Le Quére et al., 2020), biodiversity loss (Keesing and Ostfeld, 2021), economic processes (Pak et al., 2020; Spash, 2020), political power struggles (Dressler, 2021), social inequality (Stiglitz, 2020; Wade, 2020), and democratic processes (Airoldi and Vecchi, 2021). Finally, they do not involve local needs and knowledge and, hence, do not enable and empower local decision-makers and communities to manage the negative social and economic consequences of the pandemic (Ostrom, 1990).

There is a clear need for initiatives or solutions designed based on precautionary approaches to decision- and policy-making, maintaining the self-regulating properties of affected systems and avoiding unforeseen and unintended consequences. Therefore, this article aims to provide a better understanding of how to generate and summon insights, strategies, or movements initiated in the Anthroposphere at varying scales, with implications for the Geo- and Biosphere according to spatial, temporal, population, or other parameters (e.g., geological, ecological, climatic).

We focus especially on the potential role of diversity in different systems embedded in the multiple spheres of the total environment, in particular health, land, knowledge, and innovation systems. Biological and cultural diversity represents a key feature of resilient and stable systems; hence, we argue that regaining diversity can provide a useful and unexplored perspective when making decisions and taking action about complex phenomena of the total environment such as the COVID-19 pandemic. Regaining diversity, however, does not imply the possibility of complete reversal, as in the epic poem "Paradise Regained" of English poet John Milton. Rather, we emphasize the need to halt trajectories of diversity loss and to learn how to deal with a multiplicity of perspectives and factors, allowing for contestation and dissent when addressing complex and contentious issues.

The solution-based discussion proposed here dispenses with a highly theoretical stance, offering instead an extended framework in relation to Cazzolla Gatti et al. (2021), in the sense that it conceptualizes a precautionary approach to the issues at hand (Section 2), before moving onto a literature-based, non-exhaustive but highly representative set of inter- and transdisciplinary proposals related to four comprehensive systems: health (Section 3); land (Section 4); knowledge (Section 5); and innovation (Section 6). A few final remarks are presented in Section 7.

## 2. Diversity, pandemics, and precautionary approaches

While corrective or reactive measures still constitute the norm in how we tackle phenomena of the total environment, several studies are calling for precautionary approaches (Folke et al., 2021; Levin et al., 2021; Polasky et al., 2020; Sahin et al., 2020; Waltner-Toews et al., 2020). The latter are above all applicable in circumstances in which (i) values (e.g., human and environmental health) are understated, (ii) irreversible and grave consequences are a possibility, (iii) urgency is just as relevant as providing the right answers, and (iv) false negatives are more harmful than false positives (Persson, 2016). As argued by Stirling (2020, 2010), this is not about increasing levels of science-based control over emergent dynamics of the interacting Anthro- Bio- and Geo-spheres. It rather means to make room for preemptive appraisal processes that can inform policy-relevant decision-making by embracing the interdependent complexities of the underlying mechanisms at play. This calls for intentional action aiming at the stability and resilience of socio-ecological systems which are sustained or regulated by different forms of diversity in all of the spheres of the total environment.

Acknowledging the role of diversity also as a solution entails asking whether it is an unqualified blanket good. The politics underlying its modern concept are often dominated by representations based on purity (e.g., pristine forests) and standardizations which disregard the value of hybrid landscapes and communities (Baker et al., 2013). Transparency in the intended specific meaning of diversity in each case can allow the precautionary framework proposed here to avoid further consolidating hegemonic institutions which stand in opposition to intended action. Attention should also be drawn to how diversity is historically produced and represented according to power structures, who gets to decide what diversity means, which diversity is deemed beneficial, and for what purposes. Only after such a reflection can we reap the fruits of diversity as a principle that "offers a means to promote innovation, hedge ignorance, mitigate lock-in and accommodate pluralism" or that "offers one important strategy for achieving qualities of precaution, resilience and robustness that are central to sustainability" (Stirling, 2007, p. 715). The concept of diversity can then be used as an organizing principle that helps to guide and frame precautionary approaches to dealing with emergent phenomena of the total environment such as the COVID-19 pandemic.

### 2.1. Precautionary approaches

Scientific investigative tools and corrective response strategies dealing with complex issues have claimed significant achievements in controlling damages and containing effects of detrimental processes. At the same time, reliance on high-quality data has shaped our interventions to be highly reactive. Rising global, regional or local issues typically take time to be acknowledged and thoroughly examined, while responses are only planned upon the availability of sufficient data. This process does provide a multitude of information for developing reaction strategies, but only at the expense of long lead times and unintended collateral damages. With accelerating rates of globalization, urbanization, and economic production, the pandemic serves as a grim reminder that we no longer have time or resources to spend while planning reactions.

Using the issues and shortcomings revealed by the COVID-19 pandemic, disease management serves as a crucial example of how reactive strategies and responses do little to mitigate damages of an unexpected global catastrophe. Disease management has been shaped by our expanding knowledge on the source of infections. Encounters with pathogens were initially dealt with by means of symptom alleviation; although crucial during any epidemic, including COVID-19 (Bajwah et al., 2020; Tanzi et al., 2020), palliation binds health security into a reactive stance. Modern health security has thus targeted disease-causing agents directly through hygienic restrictions (Lane et al., 2010), food safety standards and sanitation protocols (FAO and WHO, 2020), mass vaccination campaigns and scenario-based exercises (JHCCB, 2001; Lakoff, 2017), interdisciplinary initiatives (AVMA, 2008; EcoHealth Alliance, 2015; IHR; WHO, 2005) and global surveillance

**CURRENT, CORRECTIVE APPROACH**  
**PROPOSED, PRECAUTIONARY APPROACH**

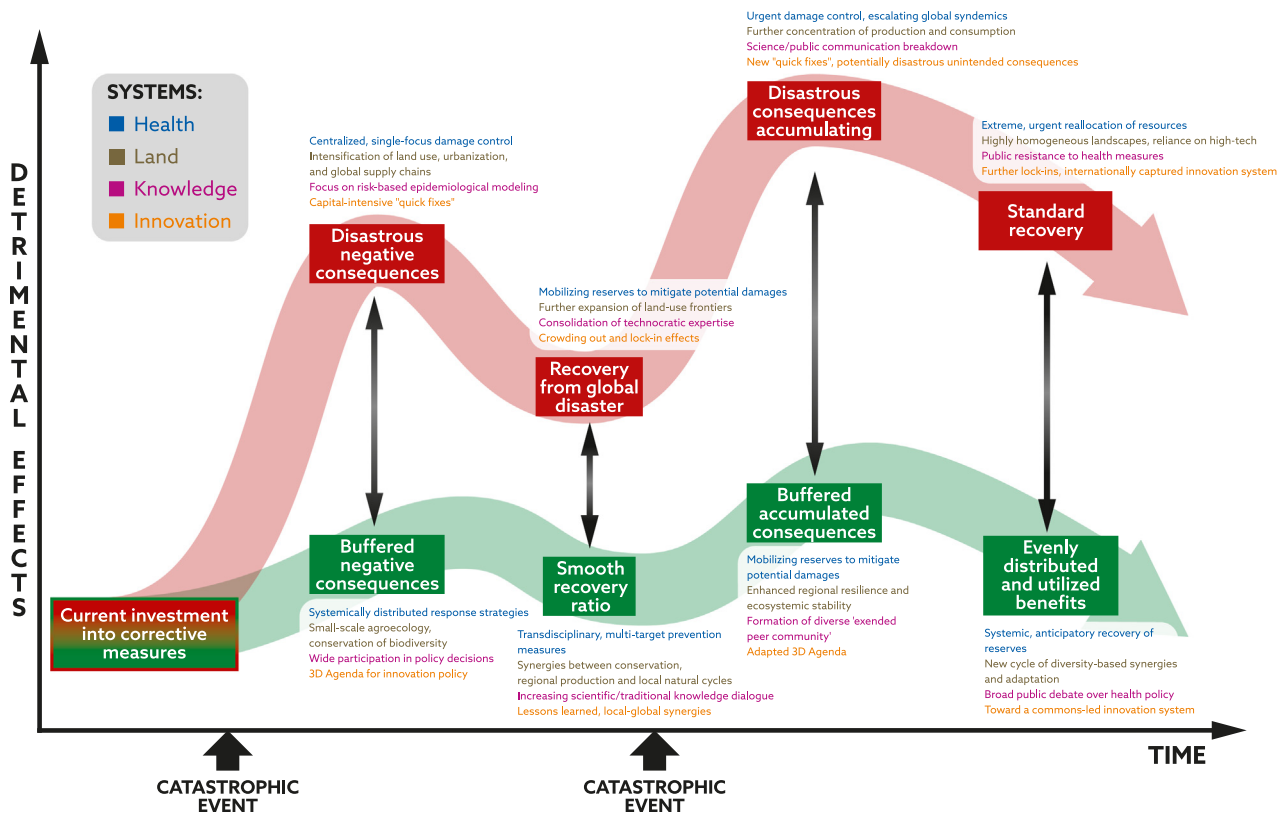


Fig. 1. The anticipated negative effects of global catastrophic events and responses to them in terms of steering factors as manifested in health, land, knowledge and innovation systems. The red curve shows predicted severity of effects with business-as-usual corrective approaches, while the green curve shows relatively smaller effects when precautionary approaches are adopted.

systems (WHO, 2000; WHO GISRS, 1952). However, despite our seemingly high level of pandemic preparedness (GHS Index, 2019), COVID-19 caught global health security off guard.

The accelerating rate of newly emerging issues across social, political and economic landscapes calls for a paradigm shift from reactive to precautionary thinking. Moreover, investments required by anticipatory approaches can be offset by their numerous advantages when compared to reactive strategies, resulting in substantially reduced costs and evaded negative effects over time (Fig. 1). Precautionary protocols allow for the prevention or buffering of many global events of catastrophic magnitude (e.g., pandemics, armed conflicts, environmental disasters, etc.). Finally, since global challenges are expected to accelerate in rate (IPCC, 2021), there is a considerable chance that the effects of such events will accumulate due to protracted recovery rates. In contrast, precautionary measures would enable us to reduce or completely avoid such accumulative processes.

2.2. Applying the precautionary approach to systems

The co-evolutionary couplings between the Geo-, Bio-, and Anthroposphere can be modelled by means of feedback loops in complex systems. Output information circles back as input and can either stabilize or destabilize the system, in the latter case amounting to a cascade of cataclysmic events (Åström and Murray, 2021). For example, the effects of feedback loops between pandemics and climate dynamics (Hofmeister et al., 2021; Phillips et al., 2020) can lead to irreversible and harmful tipping points.

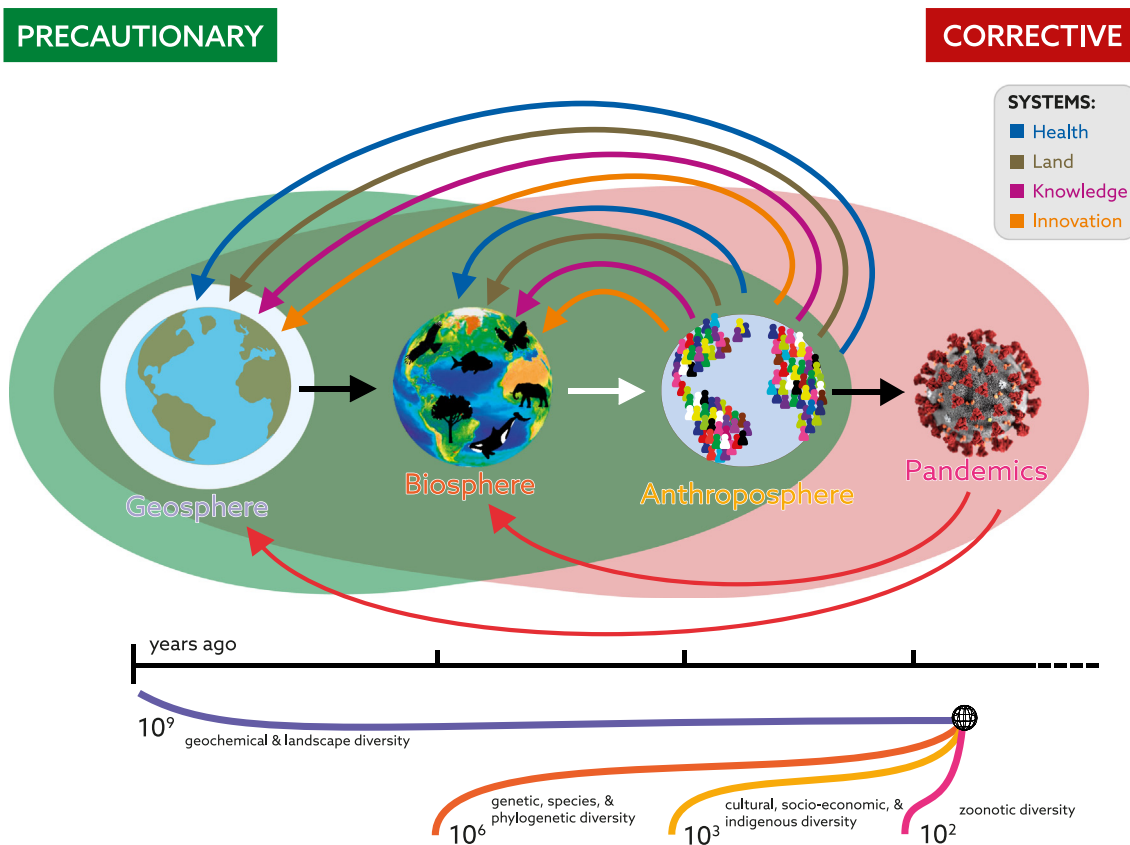
Thinking in terms of systems is helpful not only for understanding and assessing feedback loops, but also for highlighting the need for scaling

between the micro, meso, and macro levels. It makes clearer which mechanism is being intervened in as well as its repercussions within the system itself and neighboring, interconnected, or nested ones (Leventon et al., 2021). A precautionary approach to systems then aims at anticipating such destabilizing feedback loops and the unintended consequences they bring by means of sustaining diversity as a principle favoring system resilience and stability.

We choose health management, land use, knowledge production, and innovation systems as exemplary rather than exhaustive realms of action. While health-related issues revolve around adequately dealing with pathogens and adapting our modes of social organization to their presence, land use focuses on social provisioning processes and international trade. Epistemic justice and the political economy of sociotechnical progress, in turn, become the center of attention when respectively addressing matters of knowledge and innovation. The dynamics underlying the four systems discussed here, each one thoroughly intertwined with the COVID-19 pandemic and pertaining to a large array of agents, structures, and mechanisms, will be presented in the following sections. Opportunities for stabilizing action informed by a precautionary framework are then offered within each system (Fig. 2).

3. Health systems

The planetary health perspective (Horton et al., 2014; Myers, 2018; Watts et al., 2020; Whitmee et al., 2015) contextualizes human communicable and non-communicable diseases in terms of ecological degradation, invasion and fragmentation of wilderness, and patterns of production, consumption, trade, and travel (Myers and Frumkin, 2020). A systems approach to health and well-being highlights the interconnectedness within



**Fig. 2.** Schematic illustration of corrective (red arrows) and precautionary (arrows colored by system) feedback loops. The former result in unanticipated consequences while the latter seek to stabilize inner dynamics based on initiatives implemented in health, land, knowledge and innovation systems. Systemic, precautionary solutions (green cloud) provide a significantly lower probability of a global catastrophic event, whereas corrective approaches (red cloud) yield few results in preventing global catastrophes such as pandemics. Adapted from (Cazzolla Gatti et al., 2021).

a dynamic, biophysical web of the total environment (Pongsiri et al., 2017), and exposes reductionism and simplification as critical threats inherent to the dominating capitalist-extractivist approach (David et al., 2021; Dillard-Wright et al., 2020; Mair, 2020; Masuda et al., 2020; Redvers, 2021). Improvements in human health and life expectancy have been unequally realized and at the expense of deteriorating natural systems, thereby jeopardizing the wellbeing of present and future generations (Atwoli et al., 2021; Myers et al., 2021; Whitmee et al., 2015). Non-communicable diseases linked to social disadvantages, industrial agriculture, and poor diets, among other determinants, merged with COVID-19 into a syndemic (Fronteira et al., 2021; Horton, 2020; Mendenhall, 2020). Mental health and diverse ways of thinking are similarly affected by the increasing homogenization of social, environmental and biophysical processes (Marazziti et al., 2021).

On the other hand, the accelerating rate at which communicable diseases arise has led to the emerging infectious disease (EID) crisis, with the ongoing COVID-19 pandemic as the latest example. Understanding the evolutionary drivers of emergence is key to breaking down the dangerous misconceptions global health security clings to, leading to the impression that emergence is a rare event preceded by drastic mutations (see Brooks et al., 2019; reviewed in Laciny, 2021). Our exploitation of the Geo- and Biosphere and the current anthropogenic climate crisis have led to migration of animal and human populations (Hsiang and Sobel, 2016; McMichael, 2015). Globalization, the expansion of urban environments, and the reliance of modern societies on connectivity, monoculture crops, and livestock have all created an immense opportunity space for pathogenic causes of EIDs, in addition to making socioeconomic systems extremely vulnerable to their devastating consequences (Bonilla-Aldana et al., 2020; Buse et al., 2018; Watts et al., 2018). Understanding these evolutionary mechanisms is a precondition

for developing proper health security measures to prevent the onslaught of future EIDs.

### 3.1. Sustainable and healthy diets

Prevailing food systems increase homogeneity on a massive scale and reduce resilience at multiple levels due to loss of diversity in terms of soils, feeds, biomass, agricultural knowledge, and ultimately diets (Lappe, 2010). Within the larger connection between human health and biodiversity (Bernstein, 2014; Dobson et al., 2006; Marselle et al., 2021), dietary diversity plays a particular role (Verger et al., 2021). Dietary under- and overconsumption, as well as diet-related non-communicable diseases - i.e., chronic metabolic, cardiovascular, (neuro-)degenerative and neoplastic diseases (Branca et al., 2019) - are established risk factors for severe COVID-19 infection (Kurtz et al., 2021; Mertens and Peñalvo, 2020; Popkin et al., 2020). Conversely, the current pandemic is projected to aggravate undernutrition in low- and middle-income countries (Osendarp et al., 2021). Diet-related inequalities reinforce an old association between economic power and health risks, and go far beyond individual biology and cognitive control of lifestyle choices (Fronteira et al., 2021; Marmot and Bell, 2019; Wade, 2020). For example, the correlation between an increasing burden of non-communicable disease and obesity in low- and middle-income countries (Bhurosy and Jeewon, 2014; Ezzati et al., 2018) needs to be seen in the context of unequal international trade patterns and restricted communal access to land and environmental resources (Buse et al., 2017; Dorninger et al., 2021a; Gálvez, 2018; Hawkes, 2006; Hinchliffe et al., 2021; Popkin, 2006; Thow and Hawkes, 2009). Establishing reference diets in accordance with the tenets of planetary health can address under-, mal-, and overnutrition, strengthen individual and community resilience, help make food systems environmentally sustainable, and



support climate resilience and adaptation (Lappe, 2010; Willett et al., 2019). Such efforts represent a key example of interventions as co-beneficial social tipping points (Otto et al., 2020). However, this does not amount to reducing food choices or advocating for “realigning beliefs” in society (pointed out in Spash and Hache, 2021). Dietary programmes in accordance with planetary health stress local food culture and food sovereignty (Willett et al., 2019; Wittman, 2011) instead of prescribing a totalitarian healthy diet for all. This approach values local ecosystem diversity and emphasizes pluralistic, participatory, and regional norms and cultures.

### 3.2. Mental health, neurodiversity and behavior

Coined in the late 1990s in the context of advocacy for individuals with autism spectrum disorder (ASD), the concept of neurodiversity has only recently gained widespread awareness and popularity (Ekblad, 2013; Hens et al., 2019). It seeks to frame neurodevelopmental and mental health conditions that affect human neurology and perception as natural variations with unique talents and views rather than stigmatizing illnesses defined by their deficits (Doyle, 2020; Jaarsma and Welin, 2012).

As an example, despite atypical patterns of social and sensory processing, individuals with ASD have been shown to thrive academically, professionally, and personally if provided with a supportive environment and accommodations (Bertilsson Rosqvist et al., 2019; Doyle, 2020; Russell et al., 2019; Yergeau, 2018). The COVID-19 pandemic has, thus, presented this population with challenges as well as alleviations. On the one hand, autism and other mental health conditions pose as risk factors for severe infections (Brown et al., 2021), and mitigating measures like lockdowns or mask-wearing have caused distress via disruption of routines and sensory discomfort (Baweja et al., 2021; Fuld, 2021; Spain et al., 2021). On the other hand, reduced social interactions and more flexibility in the workplace have increased accessibility and decreased stress and anxiety for many individuals struggling with these issues (Spain et al., 2021). These examples illustrate how differentiating disabled or mentally ill from so-called healthy individuals may strongly depend on context and environmental conditions (Hens et al., 2019; Syme and Hagen, 2020). Carrying these lessons and accommodations into a post-pandemic future would increase the diversity and accessibility of working environments in general (Weitzer et al., 2021).

In many aspects of social interactions, COVID-19 caused deviances such as bouts of panic buying at the early stages of the outbreak (Arafat et al., 2020), and long-term effects on consumer behavior might be more widespread (Cambefort, 2020; Sheth, 2020). Apart from a surge in e-commerce or a trend towards buying essentials in bulk (Arora et al., 2020), a general psychographic shift in beliefs and ensuing buying behavior seems possible (Zwanka and Buff, 2021). This shift might also increase the complexity of behavioral options, thereby transcending the logic of consumerism as such. Supporting this assumption, the pandemic indeed stimulated reduced consumption levels, making room for behavioral patterns known as frugal consumption (Mehta et al., 2020) or voluntary simplicity (Çinar, 2021). Voluntary simplicity has been associated with increased well-being (Osikominu and Bocken, 2020; Tosun and Sezgin, 2021). Similarly, an increased engagement with natural environments has also proven helpful during the uncertainty of the pandemic, particularly for those with mental health issues (Willoughby, 2021). Therefore, hypothesizing voluntary simplicity and similar lifestyles as a moderating factor in understanding the effects of COVID-19 on public health systems might introduce alternative perspectives.

On a larger scale, the success of these approaches is in line with One Health, Green Care, and similar paradigms linking local and global ecosystem health to human physical and mental wellbeing (Bonilla-Aldana et al., 2020; Bratman et al., 2019). Therefore, future public health strategies should consider the importance of creating spaces and opportunities to accommodate the full range of human bodies, minds, and perceptions. This will ultimately affect our interaction with and appreciation for the Geo-

and Biosphere, thereby allowing diversity at the micro scale to feed back into larger contexts (Cazzolla Gatti et al., 2021; Marselle et al., 2021).

### 3.3. Prevent: the novel approach

Current state-of-affairs requires that we address the threat of pathogens before they manifest themselves as contagious illnesses. This new addition to disease management strategies is also based on intersectoral collaborations between evolutionary biology, phylogeny, public health and science policy. “Document, Assess, Monitor, Act”—DAMA (Brooks et al., 2019)—is a comprehensive, proactive action plan, serving as a precautionary framework and complementing current practices focused on responding to already emerged diseases.

**Documenting** processes information on microbe species, many of which bearing pathogenic potentials. Disease-causing organisms in humans, crops, and livestock reside in at least one additional host that is not diseased (Brooks and Hoberg, 2000). Such reservoir hosts are often known or suspected, allowing us to focus on a manageable subset of all the species. Information on novel microbes and assemblages is generated by virologists and bacteriologists as well as citizen science collectives.

**Assessment** is based on detecting genetic relationships of newly identified microbes to reveal their closest kins. Conservatively inherited traits result in similar characteristics between closely related species; pathogenicity of their kinship therefore serves as an adequate indicator of microbes' pathogenic potential. Phylogeny and taxonomy have extensive experience and long-term databases on necessary genetic information, and can assign novel species into high and low risk categories from a public health perspective (Dunnum et al., 2017).

**Monitoring** focuses on species that have been deemed to pose high risk, and maps the distribution of their reservoir organisms to determine interfaces between the Biosphere containing reservoirs and the Anthroposphere with potential hosts such as livestock or human populations. We are looking for change – in geographic distribution, in host range, in transmission dynamics, in geographic variation, and early signs of arrival of anticipated pathogens. Population, urban and behavioral ecologists possess comprehensive datasets on reservoir migration and behavioral patterns, and provide a substantial contribution to prevention efforts.

**Action** is then taken to prevent crossover from reservoirs to human or economically relevant species. Identifying the exact location and type of interfaces will allow for a public health intervention such as adjusting food safety measures, relocating reservoirs, redesigning educational programs or altering animal husbandry regulations. Sectors involved are public health, veterinary health, agriculture, disaster preparedness, tourism, and infrastructure (Bajer-Molnár et al. *under review*).

The DAMA protocol is to be integrated into existing disease control initiatives, using previously developed infrastructures and best practices. It complements our current measures by aligning our defence strategy with the threat of newly emerging diseases and establishes precautionary global health security.

### 3.4. The crucial role of community engagement

Traditional disease surveillance tools can be limited by countries' jurisdictional boundaries and logistics, while large-scale surveillance is associated with high cost (Palmer et al., 2017), limiting public health protection. Citizen or Community Science (CS) offers a solution to this problem, as a complementary tool in the pandemic prevention toolbox. CS refers to ‘the practice of non-professional participation in scientific research, including data collection, to support scientific investigation and knowledge’ (Gadermaier et al., 2018; Gura, 2013; Haklay, 2015). CS has made significant contributions to biodiversity assessment across the world (Haklay, 2015; Marizzi et al., 2018). CS has also been particularly effective at identifying threats to species diversity (Billaud et al., 2021), partially due to high motivation of local communities to combat them. Along the same lines, community science efforts monitoring invasive mosquito species serving as vectors for various pathogens have shown promising

results (Bartumeus et al., 2018; Braz Sousa et al., 2020; Magnussen and Stensgaard, 2019; Tarter et al., 2019; Tyson et al., 2018; Walther and Kampen, 2017) (see also [www.mosquitoalert.com](http://www.mosquitoalert.com); <https://mueckenatlas.com/about/>).

Other initiatives go beyond sole-species identification and demonstrate the role of CS as a sentinel for viral surveillance in detecting EIDs. Co-created with the community, the New York City Virus Hunters program generates crucial data on the prevalence of avian viruses in urban wild birds residing in or migrating through New York (Chait, 2020). Monitoring of viruses such as avian influenza in urban reservoirs that can infect a wide range of birds, and, in some cases, humans, could serve as an early warning system for EIDs. Spearheaded by urban youth, the initiative also provides underserved high school students with in-demand skills by providing authentic, professional research experience under expert mentorship (Wu, 2021). In addition, the NYC Department of Health and Mental Hygiene reports influenza and pneumonia kill 2200–3000 residents each year, the city's third leading cause of death. Black and Latino New Yorkers are less likely than white and Asian residents to get the influenza vaccine, and there is high neighborhood variation, with lower-income neighborhoods demonstrating lower vaccination rates. A closed feedback loop ensures that program participants take the data they generate directly to their communities, increasing influenza awareness and potentially improving vaccination rates among the least-vaccinated populations in the long term.

#### 4. Land systems

Reducing human impact on natural ecosystems by means of forestalling the expansion of land-use frontiers is the most obvious solution to regaining biodiversity and consequently preventing future pandemics. It could be accomplished, for example, by shifting from animal-based diets and their comparatively higher needs for productive land to plant-based diets, incurring a lower demand for fertile land ecosystems and freeing up primary production—i.e., trophic energy and biomass—for maintaining other species (Kastner et al., 2012). At the same time, the metabolic pressure of human societies over land systems is likely to increase, with vast amounts of productive land being required to produce biomass for food, feed, shelter, and, given a scenario of energy transition, bioenergy production (Rathmann et al., 2010). Hence, a precautionary approach to pandemics also entails dealing with global land use management, namely making decisions and taking action against a backdrop of complex interdependencies emerging when combining preservation of geo- and biospherical diversity and social provisioning processes.

Protecting land for the sake of conserving biodiversity is also a first reaction to the emergence of a zoonosis (Cazzolla Gatti, 2020; Turcios-Casco and Cazzolla Gatti, 2020). Measures such as reforestation, ecological restoration, and rewilding can be considered some of the most effective ways we currently have to protect ecosystemic health and regain biodiversity, on which human health also depends (Cazzolla Gatti et al., 2021). Setting aside more land as exclusive wildlife habitats can be achieved via reduced total land-use requirements (as illustrated above) and shielding natural environments from human economic activities. The latter may contribute to diminishing the likelihood of zoonotic transmission. Nevertheless, ensuing high levels of geographical specialization and concentration of economic production and consumption, including monoculturalism and large-scale industrial livestock-rearing, might also lead to higher degrees of vulnerability and susceptibility to virus transmission typical of particularly dense and anthropized areas (Rulli et al., 2021; Sun et al., 2020).

Recent research indicates that while developed nations are indeed able to spare land either for biological conservation, recreation, or as environmental sinks, this is usually possible due to outsourcing land use to less developed and populated nations and the industrial intensification of land use (Dorninger et al., 2021b). However, local short-term optimization of land-use systems does not lead, as a general principle, to global sustainable land use. For example, current industrial food production and distribution systems cumulatively cause 34% of anthropogenic greenhouse gas emissions (Crippa et al., 2021) and precipitate environmental degradation

(Dudley and Alexander, 2017; Garnett, 2013; Willett et al., 2019) as well as EIDs (Jones et al., 2013; Rohr et al., 2019).

Therefore, alternative solutions pertaining to the land system stress small-scale and rural communities as integral to the conservation of biodiversity and maintenance of long-term social-ecological resilience (Brosius et al., 2005; Fairhead and Leach, 1996; Lansing, 1991). Indeed, humans have for millennia shaped and managed diverse landscapes (Cronon, 1996; Levis et al., 2018; Lombardo et al., 2020), although the rise of large-scale capitalist exploitation techniques has brought with itself a dangerous disarray in human-nature relations (Büscher and Fletcher, 2020; DePuy et al., 2021). Traditional agroecological practices from swiddening (Conklin, 1957) to the creation of forest mosaics (Fairhead and Leach, 1996; Velásquez Runk et al., 2010) and pastoralism (Donihue et al., 2013) have been shown to have less impact on biodiversity than industrial agriculture, while providing humans with sustainable and sufficient livelihoods. Fundamental principles of agroecology include smallholdings, short supply chains, income for rural families, increased food sovereignty, cooperative models, and the protection of biodiversity (Jumba et al., 2020). Thus, agroecology entails a fundamentally different vision of how to produce and consume food and, while doing so, it aligns land use with a precautionary response to future pandemic outbreaks (Altieri and Nicholls, 2020; Loker and Francis, 2020). Such lessons underscore the importance of thinking of mutually beneficial relations between humans and nature in anthropized areas, with local communities involved in conservation policies (Brosius et al., 2005; West et al., 2006) and more “integrative” (Esposito, 2002) approaches to conservation that support the complexity and diversity of the total environment (Baker et al., 2013; DePuy et al., 2021).

The complexity involved with associating diversity-driven concerns and human land use is illustrated by the issue of insects in agriculture. While sustainable farming practices and an awareness for the welfare of common insect pollinators (e.g., honey bees) are on the rise (Hevia et al., 2021), monocultures still represent the global majority of crops (Altieri and Nicholls, 2020). Reduced diversity and the rapidly changing composition of animal and plant assemblages by human intervention and aggravated by climate change have made these vast agricultural landscapes extremely vulnerable to disease and insect pests, only maintainable via genetic and agrochemical technologies (Altieri and Nicholls, 2020; Liu et al., 2018). Pesticides are known to not only harm herbivorous insects, but also beneficial pollinator species and predators (Hevia et al., 2021; Schläppi et al., 2021). Furthermore, pesticide exposure can be harmful to human health and has even been implicated as a risk factor for severe outcomes in COVID-19 infections (Petroni et al., 2020).

Another issue pertaining to a precautionary approach to land systems is the shift from capital-intensive, highly technological fixes that are inherently corrective in character to the use of so-called appropriate or intermediate technologies. These technologies promote a context-specific, organizationally situated development and manifest themselves through the application of tools, machines, and materials using locally available resources for the sake of improving well-being while avoiding unintended or undesirable cultural and environmental disruptions at the regional level (Dunn, 1978; Schumacher, 1973 [2010]). The adoption of intermediate technologies fosters resilient and labor-intensive forms of food production as well as energy, water and waste infrastructures which dispense with massive investments and avoid profound interferences with the landscape (Akubue, 2000; Murphy et al., 2009; Patnaik and Bhowmick, 2019; Sianipar et al., 2013). Furthermore, they discourage large-scale livestock production and exploitative industrial meatpacking facilities that, on top of their ecological harm, have also become hotspots of COVID-19 outbreaks (Taylor et al., 2020).

Hence, alternative solutions aimed at regaining diversity and preventing future pandemics stress and acknowledge both the need to preserve natural ecosystems and that humans are an integral part of their environments, relate to them in different ways, and can actually contribute to their health, highlighting the political dimension of negotiating access and rights to natural resources. Such solutions would include agro-ecological efforts of

regionalizing the bulk of biomass production and consumption re-embedded in local natural cycles (Dorninger et al., 2021b), increase of biodiversity in human-cultivated systems (Altieri and Nicholls, 2020), the application of low and intermediary technologies in land-use activities (Murphy et al., 2009), and the adoption of integrative approaches to conservation (Büscher and Fletcher, 2020).

These approaches to conservation do not imply further industrial encroachment on hitherto unexploited natural ecosystems and their biodiversity. Neither do they favor further land cover change. On the contrary, they make the case for regaining diversity in already inhabited and economically developed territories, where protecting diversity goes beyond the Geo- and Biosphere to include hybrid human-natural systems (Baker et al., 2013). While conserving and regaining wilderness can be fostered by staving off the appropriation of additional land for economically productive purposes, areas which have already gone through this process can be revamped so that they also benefit from higher levels of diversity in their Geo-, Bio-, and Anthroposphere. Combined, these proposals amount to precautionary, context-specific solutions with the potential to increase diversity in land use and conservation, thereby reducing the risk of future pandemics.

## 5. Knowledge systems

Traditional approaches to the generation and application of scientific knowledge are proving inadequate to the task of protecting us from complex phenomena such as the rapid spread of zoonotic pathogens. The current pandemic response has highlighted that a narrow focus on quantitative measures such as total cases and deaths and risk-based epidemiological modelling fails to sufficiently address interdependent social, cultural, and political factors which must be taken into account in order to enable policy measures that are more contextually relevant and effective. Unintended consequences and intrinsic uncertainties pertain not only to aspects of disease transmission, its evolutionary pathways, medical effects—particularly long-term—and immune responses, but also to those that cannot be solved by simply more “hard data,” such as the non-linear responses of individuals and communities to social-distancing guidelines, lockdowns, or the shifting messages of scientific experts themselves (Caniglia et al., 2021; Leach et al., 2021; Lohse and Bschor, 2020; Waltner-Toews et al., 2020). Hence, we argue that the current predicament strengthens calls for the sort of precautionary approach mentioned above, particularly in relation to the socio-political aspects of science, moving beyond the inadequacies of the present by embracing epistemic diversity while grounded in the ethical principles of justice and inclusivity. In a landmark paper, Funtowicz and Ravetz (1993, p. 744) described just such an epistemological approach, which they labeled a “post-normal science” for when “facts are uncertain, values in dispute, stakes high and decisions urgent.” We can think of no better descriptor for our present moment.

The term “epistemic diversity” is here deemed both as a means and an end. The idea that diversity of evidence, methods, and perspectives leads to greater debate and deeper understanding, thereby enhancing the “objectivity” of epistemic results (Oreskes, 2019). This is not to substitute pseudoscientific claims for the evidentiary basis of science, but to strengthen the democratic scrutiny that is essential to both sound science and its application in policymaking (Airoldi and Vecchi, 2021). Indeed, the “alternative facts” of the “post-truth” moment seek to shore-up incumbent interests against inconvenient truths (Neimark et al., 2019) rather than affirming a diversity of inherently partial yet contextually-relevant knowledges (Haraway, 1988; Mitchell, 2009). Epistemic diversity might also be recognized at micro-, meso-, and macro-scales: from individual cognitive and experiential differences at the micro end (see Section 3); to the diversity of knowledges pertaining to differently situated and intersecting ethnic, gender, class, professional, and other identities (Crenshaw, 1991); and the knowledge amassed by powerful organizations and institutions of government at the macro

end, all of which play a role in how we cope with outbreaks such as COVID-19. Despite their best efforts, states and powerful institutions are often blind to complex realities on the ground (Scott, 1998), a phenomenon paralleled at the individual level by the “hubris syndrome” of powerful elites documented in neurological research (Owen and Davidson, 2009). Thus, we propose that only by deliberately and proactively making room for diverse knowledges from below can decision-making authorities take account of multiple perspectives, values, and forms of knowledge to enable a fuller understanding of the sociological aspects of disease and of human behavioral responses to public health measures. Building on calls for inter- and transdisciplinary approaches to knowledge for sustainability (Caniglia et al., 2020; Fazey et al., 2020), as well as for decolonizing scientific knowledge production (Raja et al., 2022; Tuhiwai Smith, 2012), we argue below that such a post-normal science with epistemic diversity at its core is essential for designing contextually appropriate measures to help us avert or at least better prepare for future global systemic crises like the COVID-19 pandemic.

### 5.1. Decolonizing knowledge for pandemic preparedness

When Western powers expanded their political, economic, and cultural dominance over all continents, they also imposed a universal paradigm of knowledge production (Quijano, 2010; wa Thiong'o, 1986). The main assumption behind this colonial perspective was that humanity and nature were separate entities. Replicating this division, humans were split into “civilized” and “uncivilized” populations, the latter including non-Western populations whose knowledge was portrayed as scientifically irrelevant or plain superstition (Ingold, 1986). Departing from such perspectives, scholars outside the Western canon have for decades argued for the need to break with the coloniality of knowledge production and validation on theoretical, methodological, political, and ethical grounds (Chakrabarty, 2000; Dussel, 1974, 1977, 1995, 1998; Mignolo, 1995; Mohanty, 2003; Salazar Bondy, 1955, 1968; Spivak, 2003; wa Thiong'o, 1986; Zea, 1969). Destabilizing feedbacks resulting from the Anthroposphere to the Geo- and Biospheres have also hinted towards the limits and negative environmental impacts of Western-style intervention and exploitation of nature (DePuy et al., 2021; de Sousa Santos et al., 2007; Escobar, 2014). This recognition has reinforced calls for decolonizing scientific knowledge and practice in such a way that the logic of coloniality—and its negative social and environmental consequences—might be arrested (de Sousa Santos et al., 2007; Mignolo, 2009).

As a counter-discourse to the dominant Western perspective premised on separation and abstraction, many Indigenous and other knowledge systems characterized by relational ontologies represent alternative paths for stabilizing our relations with nonhuman entities in the Geo- and Biosphere (DePuy et al., 2021; Escobar, 2014). A lesson on how to deal with an epidemic (or other kinds of systemic) crisis could be learned from Native American communities for whom the expansion of subjectivity to include the non-human realm has formed an act of resistance to the negative impacts of Western exploitation for 500 years (Galeano, 1982; Krenak, 2020). Cosmovisions that recognize our interdependent relationality with non-human beings offer a valuable counterweight to the reductionism of much of modern science. Such holistic perspectives remind us to treat non-human organisms not as alien beings removed from our moral universe, but as participants in the same world in which we are wholly enmeshed (Ingold, 1986, 2000). The separation of humans from nature, as well as domineering aims for control associated with Western science, have been decisively challenged by the current pandemic (Segato, 2020). The virus's transmission from original to intermediate host and then to humans implies that we belong to nature and are subject to its stochastic processes. Learning from traditional knowledge systems that emphasize our interdependence with nature would lead us to recognize ourselves not as disembedded from the natural world, but rather relationally constituted within it.



## 5.2. Politics of implementation

Implementing epistemic diversity in practice is, of course, the hard part. To only acknowledge the existence of this diversity risks exaggerating the differences between traditional and scientific knowledge (Agrawal, 1995; Ingold and Kurttila, 2000), when in actuality both often use heuristic strategies that encompass reductionist and holistic features according to their needs (El-Hani et al., n.d.; Ludwig and Polisei, 2018). However, the bearers of such knowledge often sit across a formidable divide of power and prestige. To bring different knowledges together in a way that opens space for equitable dialogue, it is necessary to grapple with their potential intersections and incommensurabilities as well as unequal power dynamics. One proposed strategy for bridging this gap is the partial overlaps framework, which explores differences and similarities in the ethical, epistemological, and ontological dimensions of knowledge between actors in often distinct positions of power (Ludwig, 2016; Ludwig et al., 2020; Ludwig and El-Hani, 2020). In such a way, a more participatory, transdisciplinary, post-normal approach to science might be conducted through “productive interactions in which research priorities, problem definitions and options are negotiated” (Scoones et al., 2020, p. 70), generating more effective responses to destabilizing systemic events, such as COVID-19 pandemic.

Still, the political and ethical challenges to be overcome must sit at the center of any effort to expand epistemic diversity as part of a precautionary approach to managing future pandemics. Costs and benefits must be distributed equally—rather than, for instance, the inequitable approach to global COVID-19 vaccine rollouts that has operated thus far—and participation not simply become another box to be ticked in otherwise business-as-usual scientific development and policymaking. Indeed, instrumental approaches to knowledge integration or co-production can often be depoliticizing, serving to erase differences of power and position, reinforce elite-dominated expertise, and diminish the creative potential in diversity (Goldman et al., 2018; Klenk and Meehan, 2015; Turnhout et al., 2020). Many efforts to bring historically marginalized voices into spaces of knowledge production and deliberation will occur outside of formal institutional channels, so there must be an appreciation for various forms of engagement, from citizen science (see Section 3) to grassroots social movements and the formation of unexpected alliances (Leach et al., 2010; Scoones, 2016; Scoones et al., 2020). Only through sensitivity to sociocultural context, differences of power and position, and the unruly politics through which these are often expressed will post-normal science’s vision of an “extended peer community” (Funtowicz and Ravetz, 1993) be diverse enough to avert catastrophic crises.

## 6. Innovation systems

The uniqueness of the COVID-19 economic recession—“a policy-induced recession”—relates to “efforts to tackle a health emergency and to save lives through containment measures and social distancing” (BIS, 2020, p. ix). The political answer to this other challenge, a financial one, was staggering. Tooze (2021, p. 244) presents the measures taken to contain the financial crisis, highlighting a contrast between such monetary, prudential and fiscal policies and support for vaccination: an “unprecedented emergence spending that dwarfed the scale of the entire vaccine program.” This contrast persists, leading to a new problem - the uneven speed and rates of global vaccination that threatens broader economic recovery (Alderman, 2021).

Discussions on the feedbacks between the pandemic and its protracted economic effects allude to the current role and challenges of innovation systems - i.e., institutional arrangements that articulate different actors such as firms, universities/research institutes, and states/governments to generate reinforcing feedbacks between science and technology underlying innovation (Freeman, 1988; Nelson, 1993). Gross & Sampat (2021, p. 29) emphasize how “the COVID-19 crisis may usher in new forms of R&D management and collaboration,” while Younes et al. (2021, p. 743) move beyond the role of innovation as an immediate response, i.e., as “urgent and compelling search for vaccines and other critical technologies,” arguing

that “[t]o prevent outbreaks (ex-ante) or mitigate their effects (ex-post), our society needs more than technological fixes. A second line of response is precautionary and calls for the production of knowledge of a rather different kind than what the first line of response is going to produce.”

Steering technological innovation systems according to a precautionary framework entails answering what the defining traits of this different kind of knowledge are as well as which policies unleash their full potential for curbing trajectories of diversity loss. The manifesto of the STEPS Centre (2010) calls for a new critical global politics of innovation, advancing an argument in favor of more deliberation, participation, and accountability in the face of unequal power relations that determine which innovation pathways will be dominant, as well as the establishment of poverty alleviation, social justice, and environmental sustainability as clear goals (see also Leach et al., 2012). It proposes a “3D Agenda” based on how innovation policy is to be guided by the principles of Direction, Distribution, and Diversity.

Examples of contrasting directions of innovation include preventive and curative approaches to public health, decentralized small-scale renewables and large nuclear or hydroelectric power systems in the context of energy transitions, and industrial agriculture and organic small-scale farming. Choices may be hard to revert, with innovation locked in dominant pathways, which means that democratic scrutiny is crucial in the face of political interests and unyielding power structures. The direction recommended by STEPS Centre (2010) highlights the role of citizen initiatives and social movements in redeeming hidden or marginalized innovation pathways, especially those in connection with securing livelihoods and complying with ecological thresholds (see also Sections 4 and 5). It is an alternative to a hegemonic, profit-driven and politically captured innovation system that suppresses other pathways and crowds out alternative directions, their context-specificity, and their distributive impacts. In addition, innovation policies targeting diversity strengthen resilience, “hedging against our uncertainty and ignorance about the future” (p. 14).

Circling back to the public health innovation example, Niang et al. (2021) show how the technological response to the COVID-19 crisis has been oriented by a techno-economic paradigm, in which innovations are always beneficial and neutral “quick fixes,” ends in themselves as they spur economic growth and productivity rather than part of a value-laden, precautionary innovation system potentially able to address complex social and environmental challenges. To Renn (2020), the task at hand calls for “global contextualism” as a simultaneous awareness of locally varying contexts and the global consequences of choices involving innovation. While the international competitiveness inherent in globalization would hinder the required transformation, a bottom-up, openly accessible and collaborative network of knowledge production could become a key public good capable of creating realistic solutions for global problems.

### 6.1. Towards global innovation systems as providers of global public goods

Innovation systems have an inner dynamic that leads to the exponential growth of international knowledge flows (Soete et al., 2010) and the formation of new layers, including one at the global level (Binz and Truffer, 2017). This process of internationalization has at least three driving forces, all directly linked to the modus operandi of institutions which compose innovation systems: (i) transnational corporations; (ii) the international character of science; and (iii) the emergence of the internet and the *World Wide Web* (Britto et al., 2021).

The process of formation of a new layer of innovation systems at global level combines different dichotomies. First, a dichotomy between intentional and unintentional forces, whereas the latter appear as dominant: transnational corporations do not deliberately plan the formation of global systems of innovation, but as multinationality in innovation processes appears to be a strong source of profits, they proceed to multiply international knowledge flows. Second, between public and private resources, as nation-states fund large portions of basic research that will later be transformed into technological applications by firms through R&D investments, whereas a bigger role of funding from international institutions might shift this



dichotomy to a global level. Third, between innovation and predation, illustrated by technological revolutions based on fossil fuels. Lastly, between commons-led knowledge creation and profit-led technology creation, as the division of innovative labor, on the one hand, necessarily draws upon science (Nelson, 2004) and knowledge as a commons—i.e., “a resource shared by a group of people” which can “extend to international and global levels” (Hess and Ostrom, 2007, p. 4) and be a natural resource or knowledge, including vaccines—and, on the other hand, upon a short-term focus on profit, usually plagued with blind spots.

Born out of those driving forces and dichotomies, the emerging global system of innovation becomes an important tool to face global problems, in contrast with the more limited capabilities of individual countries and their national innovation systems. Hence, a global system of innovation can act as a provider of global public goods (Buchholz and Sandler, 2021, p. 488), defined as presenting “partially or fully non-rival and non-excludable benefits that affect a large swath of the planet” (i.e., benefits whose use or consumption by one agent does not detract from the use of others, and which can be accessed by all agents). While vaccines can be good examples of such global public goods, the category also applies to types of innovation which fit into the precautionary framework proposed here, which are likely to be supported by public labs and CERN-type cooperative scientific endeavors focused on issues bearing on different kinds of diversity, as well as mission-oriented projects which could put transnational corporations to work for these types of innovation (Freeman, 1996).

The provision of a specific set of global public goods supporting diversity in each sphere of the total environment may be proposed as a goal of a global system of innovation. It would enable a systemic view of problems and solutions arising from the implementation of new technologies over time. Moving away from profit as a driving force of innovation, it would offer alternative paths less prone to unintended consequences. It would be able to identify links such as how successful innovations in one country can lead to detrimental effects elsewhere, and impose realistic limits to action, avoiding incursions into technological *naïveté*. It would account for the importance but insufficiency of short-term solutions such as COVID-19 vaccines in the face of the increasing likelihood of future outbreaks (Brooks et al., 2019).

The emergence of a global system of innovation and accompanying new knowledge can feed back into the orientation of innovation systems themselves, defining new targets for innovative processes (Hinchliffe et al., 2021). This reorientation in the direction of technological processes relates to an increasing role of the internationalization of public funding (e.g., the 2020 increase in global military spending alone, US\$ 50 billion [(SIPRI, 2021)], would be enough to finance a broad global vaccination project [(Tooze, 2021, p. 243)]); a disentanglement between innovation and predation, as innovation is used as a means to overcome predatory techniques in accordance with an intentional, collaborative process of political goal-setting and action that accompanies the establishment of such a global system of innovation; and a strengthening of the commons-led production of knowledge, an ongoing process in current innovation systems at different layers - local, regional, sectoral and national.

Furthermore, the proposed reorientation and goals of innovation processes at global level need to be coupled with other political debates, as in the case of social inequality and the creation of a global tax on capital (Piketty, 2017), which could jointly foster an international process of institutional building, including the strengthening of the WHO or even the formation of an international welfare system (Rosenstein-Rodan, 1984, p. 221).

## 7. Final remarks

Tackling COVID-19 as a phenomenon of the total environment, as argued here, entails a systemic and precautionary approach to human-nature relations, which we frame as regaining diversity in the Geo-, Bio-, and Anthroposphere. Its implementation requires nothing short of an overhaul in the way we interact with and build knowledge from natural and social environments. Furthermore, it bears upon different facets of our

socioeconomic and political modes of organization. As an introductory exploration of the potential of a systemic and precautionary approach to current and future pandemics, we discussed four systems subject to transformations. Health systems were in the forefront of containing the disease, and are expected to be in a similar situation should a new global disease appear. Taking into account the post-pandemic state of health-care infrastructure across the world, it is crucial that their burden be eased through adapting preventive strategies such as the ones discussed here. While health systems deal directly with the effects of a pandemic, land systems refer to spaces where novel pathogens emerge. A systemic view is key in anticipating potential consequences of human-nature interactions, and allows us to develop diverse and resilient socio-ecological systems preventing emergence. The foundation for shifting various approaches towards precaution is adopting diverse forms of knowledge. Whether it concerns managing or preventing novel diseases, the COVID-19 pandemic highlighted the shortcomings of uniform, reductive analyses and management strategies oblivious to social or economic contexts and thus providing limited results in halting the spread. Increasing epistemic diversity allows systemic, preventive solutions to be fitted to the population/sector in question and thereby significantly increases their efficacy. Finally, adjusting innovation pathways towards a precautionary stance contributes to prevention in various ways. Diversifying technological developments and questioning their purposes might alleviate concentrated economic effects of a global catastrophe, unlike the current structure of locked-in trajectories. Furthermore, a systemic view facilitates communication between innovation agendas, science and society, and provides opportunity to steer developments towards preventive technologies as global public goods, such as anticipatory vaccine production.

Our reflections offer a glimpse of the sort of radical change necessary for regaining diversity. They also help to identify emergent concepts paving the road towards a paradigmatic shift, such as amplifying community engagement, relying on a shared pool of resources at the global level and encouraging sufficiency principles at the local end. The COVID-19 pandemic struck humanity completely unanticipated, and its effects continue to ripple across every layer of society and economy. The most important lesson to be learnt is that our current approaches can neither prevent nor mitigate damages and unintended negative consequences of a similar global event. A paradigm shift is therefore of the essence to avoid having to relive the past two years. For that purpose, we must not only take into account but also capitalize on the interconnectedness of humans and natural ecosystems.

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The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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